Grass-based Farming Systems: Soil Conservation and Environmental Quality

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"The soil comes first. It is the basis, the foundation of farming. Without it nothing; with poor soil, poor farming, poor living; with good soil, good farming and living. An understanding of good farming begins with an understanding of the soil."—Ahlgren, in Stefferud, Grass: The 1948 Yearbook of Agriculture, *p. 425*

Crop selection and sequence can have a profound effect on the environment and on farm profitability. Consequently, the basis for a productive agricultural system should utilize natural processes to supply and cycle nutrients, control pest populations, and maintain the checks and balances within the agroecosystem. Continuous production of the same crop often leads to a decline in yield for a variety of reasons, even with sufficient nutrient inputs. For centuries, farmers relied on crop rotation to maintain or enhance crop yield. Using forage grasses and legumes in rotation with summer annual or winter annual row crops can supply nutrients to subsequent crops that can decrease the need for purchased inputs. Perennial forage crops protect the soil from wind and water erosion and use nutrients more efficiently than row crops that are usually only growing during a fraction of the growing season. Using perennials to establish permanent grasslands on highly erodible soil can eliminate almost all soil erosion. Crop rotations including perennial forages usually have soils with higher organic matter because continuous root formation, growth, and death contribute carbon to the soil. Furthermore, land in perennial forages is not tilled, which lowers oxidation losses of soil organic matter. Organic matter inputs help increase the soil water holding capacity, which can help maintain crop growth during periods with below-average rainfall.

Despite these benefits, production of perennial forages dropped in the United States during the 20th century. Reasons for this decline include the development of pesticides, the expansion of fertilizer manufacturing, and changing rations for ruminants—animals, such as cattle and sheep, with a four-chambered stomach digestive system—the primary consumers of forages. External inputs for crop production substitute for the ecological role crop rotation provides by breaking pest cycles and using forages to supply nitrogen to subsequent crops. The environmental effect of this paradigm shift has resulted in the creation of federal agencies and policy to regulate, research, and promote environmental stewardship. It remains unclear how emerging and future markets for agricultural products will affect the environment. Potentially, landscapes covered with perennial grasses and legumes can play a dominant role in stabilizing soil and water resources, provide feed for ruminants and herbivores, and contribute biomass as a source of biorenewable energy.

FARMING SYSTEM CHANGES

Before projecting future grass-based agricultural systems and discussing how they may affect the sustainability of soil, water, air, and human resources, we need to first to examine how American agricultural systems have changed during the 60 years since *Grass: The 1948 Yearbook of Agriculture* (Stefferud, 1948) was published (see Table 7–1). Most notably, many small, diversified family farms have combined into larger specialized row-crop and/or concentrated animal feeding operations (CAFOs). The decreasing number of farms, combined with increasing productivity, has resulted in a concentration of production such that large family and nonfamily farms now account for more than 75% of U.S. agricultural sales. Between 1950 and 2000, these changes were driven by rapid advances in technology and a strong desire to produce abundant, cheap food for domestic and global markets.

Consolidation of U.S. farms significantly reduced the land area devoted to all types of hay (20% reduction), oat (*Avena sativa* L.) (90% reduction), rye (*Secale cereale* L.) (65% reduction), and barley (*Hordeum vulgare* L.) (55% reduction) crops, as well as the number of dairy cattle between 1950 and 2000. For dairy operations, these changes have also involved a transition from predominantly grazing to CAFOs (Fig. 7–1), although this has increased per animal milk production by more than 240%. Among grain crops, rice (*Oryza sativa* L.) production has almost doubled during this period, while soybean [*Glycine max* (L.) Merr.] production has increased almost fivefold (Table 7–1). The rapid expansion of soybean production began during the early 1940s, when U.S. imports

Table 7–1. Change in U.S. farm structure, animal, and crop production from 1950 to 2000.† (1 million acres = 405,000 ha; 1 lb = 0.45 kg)

Parameter	1950	2000
Number of farms (million)	5.4	1.9
Average farm size (acres)	216	487
Productivity index (output/input)	0.46	1.19
Price index ratio (paid/received)	1.01	0.44
Total cattle and calves (million)	78.0	106.3
Dairy cows (million)	21.9	9.2
Milk production (lbs per cow)	5,314	18,197
Hogs and pigs (million)	62.3	59.1
Broiler chickens (million)	631	8741
Turkeys (million)	70.7	268.1
Corn for grain (million acres)	82.8	79.6
Cotton (million acres)	18.8	15.5
Rice (million acres)	1.6	3.1
Soybean (million acres)	15.0	74.3
Hay, all types (million acres)	75.2	60.4
Barley (million acres)	13.0	5.8
Oat (million acres)	45.0	4.5
Rye (million acres)	3.7	1.3
Wheat (million acres)	71.3	62.5

† Compiled from USDA Economic Research Service (http://www.ers.usda.gov) and USDA National Agricultural Statistics Service (http://www/nass/usda/gov).

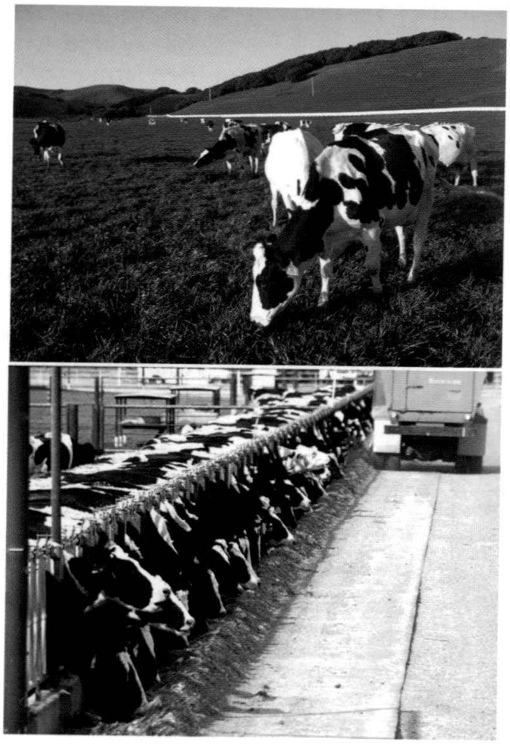

Fig. 7–1. The number of grazing dairy cattle gradually diminished between 1950 and 2000 as milk production per animal increased more than 240%. (Photo, USDA, Natural Resources Conservation Service)

of edible fats and oil were cut by 40%. Through public and private investment in plant genetics, processing techniques, and new uses, the crop's popularity expanded exponentially. The trend is expected to increase on the basis of projections that biodiesel production capacity alone is expected to increase to 2500 million gallons (9500 million L) in 2008 compared with only 2 million gallons (7.6 million L) in 2000. Now grown in more than 30 states, soybean is the second-largest cash crop in the United States.

Land devoted to corn (*Zea mays* L.) production during the past 60 years was relatively stable (Table 7–1), but grain yields increased steadily. Recent interest in producing ethanol from corn grain has raised grain prices and resulted in an increase in U.S. acres devoted to corn production. The expansion of U.S. corn acreage has been driven primarily by the creation of new markets for fuel ethanol. In 2007 in the United States, 125 plants (with a capacity of 6095 million gallons per year [MMgy], or 23,072 million L per year [MMly]) were converting feedstock, predominantly corn, into ethanol for fuel use with another 62 under construction (4702 MMgy [17,799 MMly] capacity). Capacity for ethanol production is increasing at a rapid pace. In 2006, U.S. capacity was 2150 MMgy (8139 MMly), which has almost tripled in slightly over one year. This compares to the 35 MMgy (133 MMly) capacity reported in 1980. Expanding markets for high fructose corn syrup, food alcohol, industrial uses, and feed and residual uses all have contributed to the increase in corn demand and acreage expansion (Fig. 7–2). In 2007, 93.6 million acres (37.9 million ha) of corn were planted, a 19.5% increase compared with 2006.

During the 60-year period since *Grass: The 1948 Yearbook of Agriculture* (Stefferud, 1948) was published, the shift toward monoculture and annual crop rotations has increased the reliance on external inputs for production. Between 1960 and 2005, total U.S. consumption of nitrogen fertilizer increased by 350% (Fig. 7–3). Total pesticide use increased by 130%, with the largest increase in herbicide use (Table 7–2). Insecticide use decreased during this time period because of new pesticides that were more concentrated and required lower application rates, as well as the development of genetically modified pest-resistant and pest-tolerant crops in the past decade. Total pesticide use increased about 325% in corn, 850% in soybean, 120% in wheat (*Triticum aestivum* L.), and decreased about 40% in cotton (*Gossypium hirsutum* L.). Pesticide inputs for these four crops accounted for

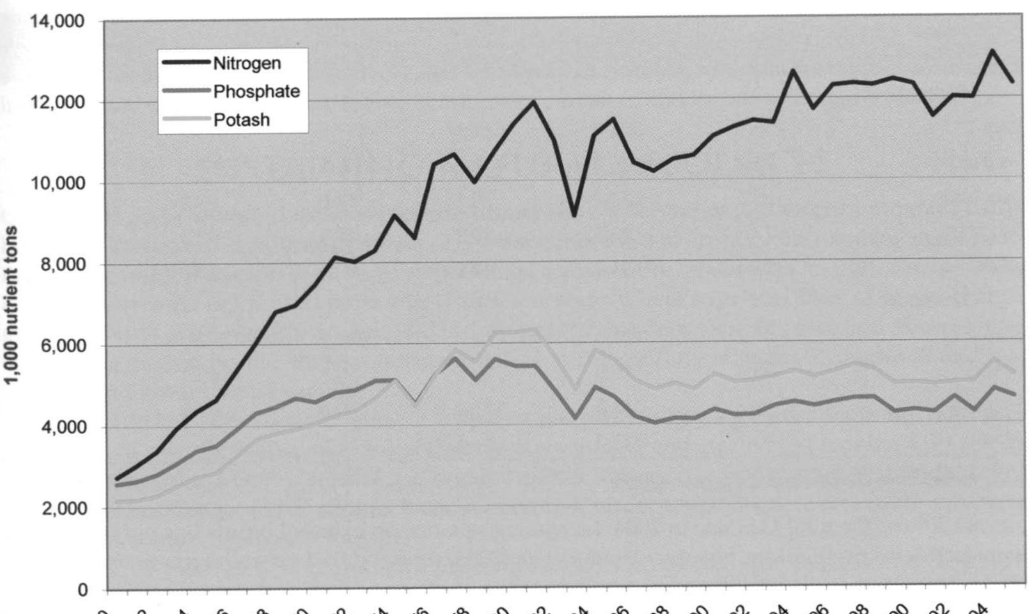

Fig. 7–2. Total U.S. consumption of nitrogen, phosphate, and potash from 1960 to 2005. Data compiled from USDA Economic Research Service (2007). (1 nutrient ton = 0.91 nutrient tonnes)

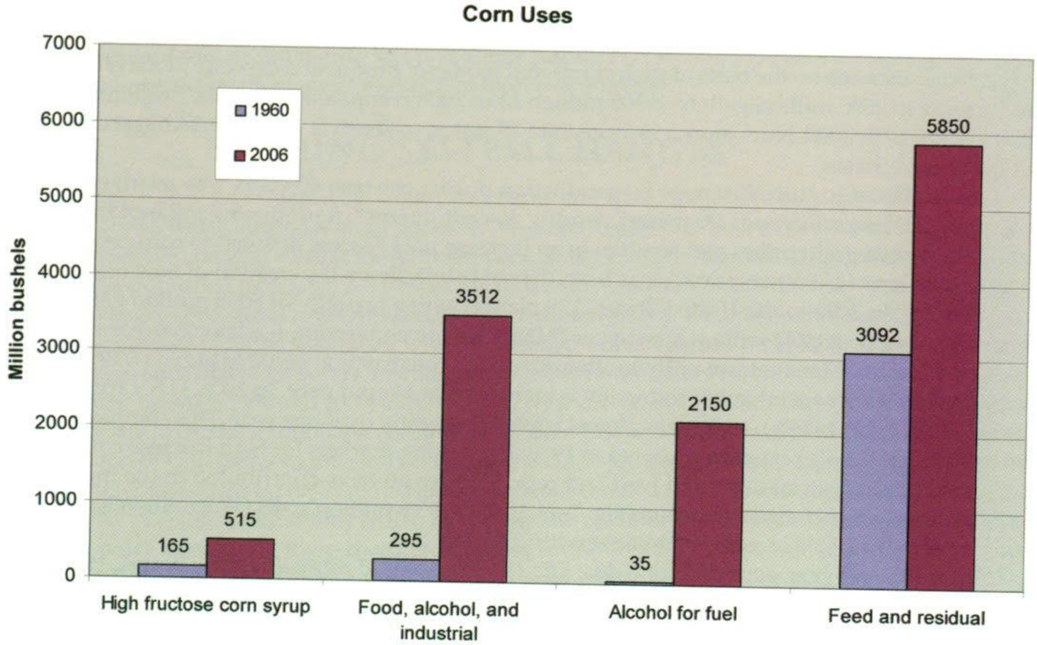

Fig. 7–3. Comparison of corn uses in 1960 and 2006. Initial data for high fructose corn syrup and alcohol for fuel are from 1980. Residual corn uses include distillers' spent grains after the starch has been removed during conversion to ethanol. Data compiled from USDA Economic Research Service (http://www.ers.usda.gov). (1 bushel = 35 L)

Table 7.2. Quantity of pesticides applied, total, and to selected crops, 1964–2004.† (1 million lb = 0.45 million kg)

Type of pesticide and commodity	Million lb active ingredient					
	1964	1971	1982	1991	1997	2004
Pesticide						
Total	215.0	364.4	572.4	477.5	579.3	494.5
Herbicide	48.2	175.7	430.3	335.2	362.6	311.0
Insecticide	123.3	127.7	82.7	52.8	60.2	40.7
Fungicide	22.2	29.3	25.2	29.4	48.5	29.8
Other	21.4	31.7	34.2	60.1	108.0	112.9
Commodity						
Corn	41.2	127.0	273.7	233.2	227.3	174.6
Cotton	95.3	111.9	49.5	50.3	68.4	56.7
Soybean	9.2	42.2	147.4	70.4	83.5	87.8
Wheat	10.1	13.6	23.5	13.8	25.5	22.3

† Compiled from Osteen and Livingston (2006).

almost 70% of the total U.S. use in 2004. Increasing reliance on external inputs has not necessarily increased farm profitability, however. Singer et al. (2003) reported that extended rotations including alfalfa (*Medicago sativa* L.) were more profitable than continuous corn and annual rotations of corn and soybean, which confirms what other work on this topic has reported. Their analysis assumed farmers had access to a forage market, which may not necessarily apply. During the last 60 years, crop and animal production have become spatially disconnected, which has favored production of grain crops for feed, which are more dense and easier to transport than forages.

SILENT SPRING

The book *Silent Spring*, by Rachel Carson, was published in 1962 and brought attention to the use of pesticides in agriculture. Carson was one of the first popular American writers to draw attention to the increasing use of chemicals to produce food and their effect on the environment.

THE ENVIRONMENTAL PROTECTION AGENCY

The U.S. Environmental Protection Agency (USEPA) was created in 1970 in response to increasing public concern about the deteriorating conditions of water, air, and land. The USEPA is an independent agency with broad responsibility for research, standard setting, monitoring, and enforcement with regard to five environmental hazards: air pollution, water pollution, solid waste disposal, radiation, and pesticides.

DDT

The general use of the pesticide dichlorodiphenyltrichloroethane (DDT) was banned on December 31, 1972 in the United States, ending nearly three decades of application during which time the chemical was used to control insect pests on crop and forest lands, around homes and gardens, and for industrial and commercial purposes. DDT was developed as the first of the modern insecticides early in World War II. It was initially used with great effect to combat malaria, typhus, and the other insect-borne human diseases among both military and civilian populations.

These trends for increased intensification of agriculture, homogenization of landscapes, and simplification of crop rotations have unfortunately been associated with the decline in other ecosystem functions, including resource protection, water supply, and pollination (Millennium Ecosystem Assessment, 2005). Soil degradation that may or may not be reversible has occurred through increased soil compaction, salinization, acidification, erosion, and loss of soil organic matter.

SUSTAINING NATURAL RESOURCES

Grasslands and cultivated forages provide numerous conservation and environmental quality benefits. Grasses can significantly lower or almost eliminate soil erosion. Best management practices to control soil erosion include grass plantings across entire landscapes, in buffer strips at the edge of cultivated fields, and particularly in waterways where overland flow of water is at its greatest. Roots of grasses are an essential binding agent that keeps soil in place and allows water to infiltrate the soil profile, thereby improving the hydrologic flow of water through soil and into seepage and groundwater outlets.

One of the key soil characteristics of land that has been in grass for decades is the high concentration of organic matter near the soil surface compared with cultivated cropland (Fig. 7–4). In the eastern United States, surface soil organic matter under grass approaches that under forest conditions, but deeper in the profile, it can exceed that under forest because of a more extensive and fibrous rooting system.

Rotation of cultivated cropland with perennial forages is not common in contemporary agriculture, but such rotations were commonplace as a means to build soil fertility before the 1940s and the development of synthetic fertilizer and pesticides. Perennial forage systems have great potential to promote soil conservation and improve environmental quality. There are a number of cropping systems for which this rotation is beneficial and economically viable. Organic agriculture

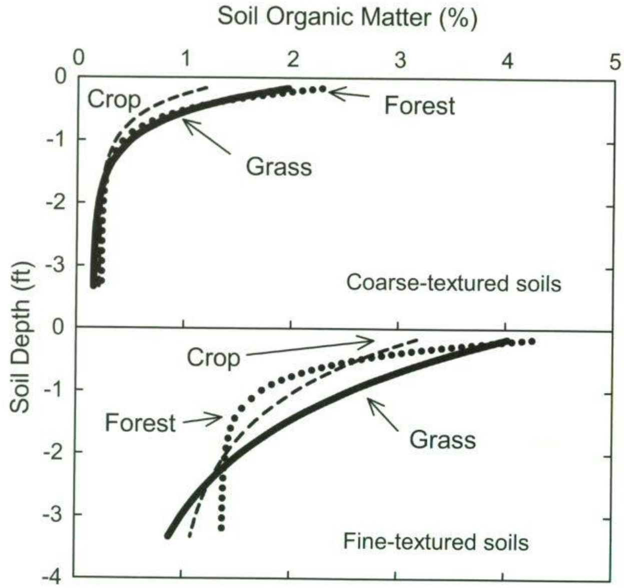

Fig. 7–4. Depth distribution of soil organic matter as affected by land use and soil textural class across a diversity of soils in the southeastern United States. Data from McCracken (1959). (1 ft = 30 cm)

is becoming increasingly attractive to a larger number of producers because of growing demand for organically raised products, and forage phases of multiyear rotations are a key element of most organic agricultural systems. Another emerging agricultural sector that relies on forage-based rotations is in integrated crop–livestock production. In the eastern United States, where precipitation is often abundant in the winter and growing conditions for a winter cover crop are favorable, diverse farming operations with cattle, sheep, or goats are being integrated with feed grain, forage, fiber, and horticultural crops. Annual cover crops provide both soil conservation and high-quality forage.

Soil loss from erosion can be managed below a tolerable limit with native or planted grasslands on slightly to moderately sloping lands. Steeply sloping land requires vigorous vegetation and limited or no traffic to avoid excessive soil loss. Research on water runoff from various parts of the world comparing grass with cultivated cropland illustrates the effectiveness of grass for controlling erosion and allowing greater water infiltration for plant uptake and groundwater recharge. Conversion of native grasslands to cropland throughout the central portion of the United States has exposed soil to wind and water erosion. Control of soil erosion is necessary to maintain soil productivity for high plant production, hydrological functioning of soil for supplying water to vegetation and recharging groundwater, the integrity and quality of surface water bodies against pollutants washed from nearby lands, and the biodiversity of the soil ecosystem.

Despite the decline in planted grasslands in agricultural rotations, grasses continue to be a key management choice for protecting water quality in streamside riparian areas and field borders. Management of these grassland buffers usually involves limited harvest to provide sufficient vegetation and residues to physically impede overland flow of water. The USDA–Natural Resources Conservation Service (NRCS) promotes grass plantings for soil and water quality improvement through forage-based crop rotations, grassed waterways, grass buffers to protect uplands, streams, and sensitive areas, improved grazing management, and most notably, the Conservation Reserve Program (CRP). Figure 7–5 presents the quantity and distribution of land converted from cropland to CRP between 1982 and 1992. During the period 1982 to 1997, soil erosion by water was reduced in part by converting highly erodible cultivated cropland into the CRP (Fig. 7–6). Soil erosion by wind was also reduced during this period by reestablishing permanent cover on highly erodible land through the CRP.

Soil under grass is often of much higher quality, as characterized by important soil properties and processes, including water infiltration and storage, nutrient cycling and storage, biological diversity, and soil organic matter content. There are a number of reasons that soil quality is

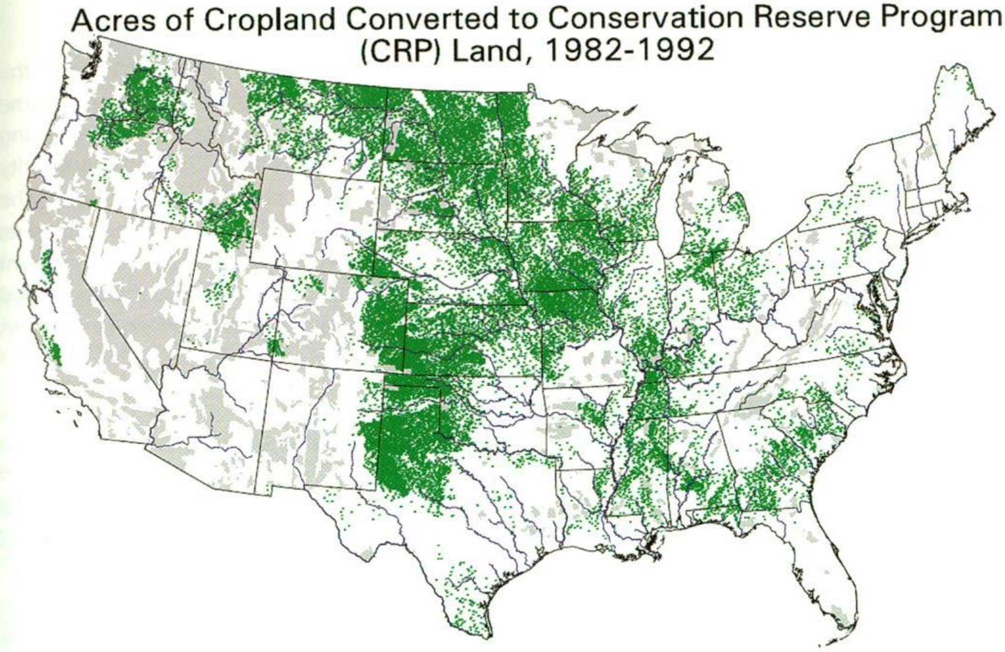

Fig. 7–5. Acres of cropland in the 48 contiguous states converted to CRP land between 1982 and 1992. Gray area = 95% or more federal area. Each green dot represents 1,000 acres. 21,756,000 total acres converted from cropland to CRP land, 1982–1992. (Source: USDA, Natural Resources Conservation Service)

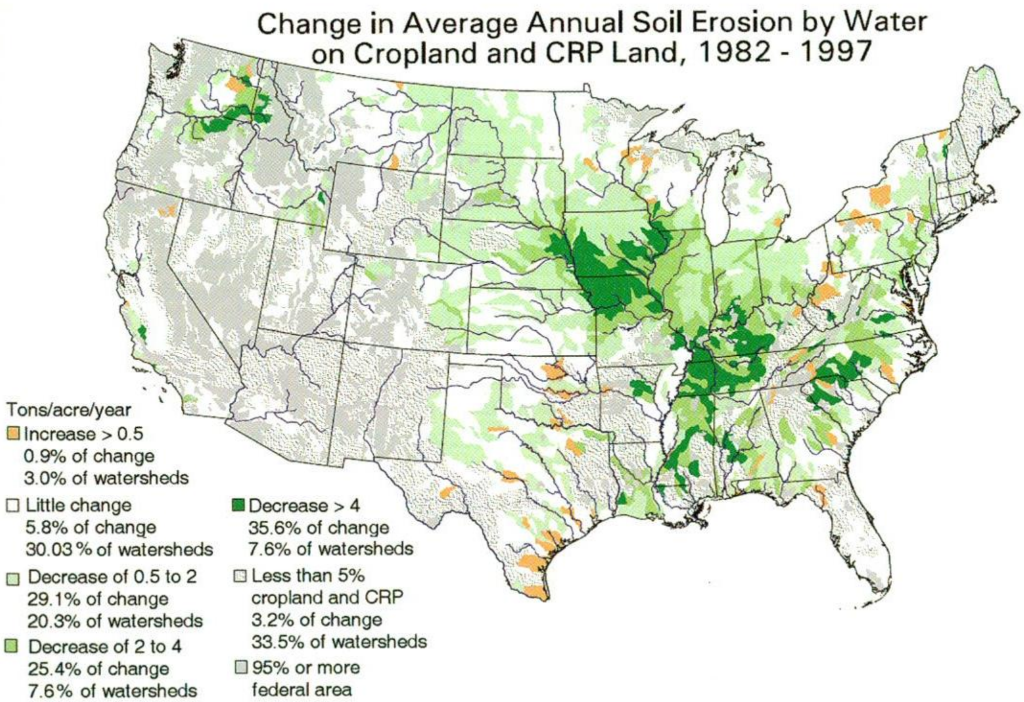

Fig. 7–6. Change in average annual soil erosion by water on cropland and Conservation Reserve Land between 1982 and 1997 in the 48 contiguous states. (Source: USDA, Natural Resources Conservation Service)

THE CLEAN WATER ACT

Growing public awareness and concern for controlling water pollution led to the enactment of the Federal Water Pollution Control Act Amendments of 1972. As amended in 1977, this law became commonly known as the Clean Water Act. The Act established the basic structure for regulating discharges of pollutants into the waters of the United States. It gave the USEPA the authority to implement pollution control programs such as setting wastewater standards for industry. The Clean Water Act also continued requirements to set water-quality standards for all contaminants in surface waters. The Act made it unlawful for any person to discharge any pollutant from a point source into navigable waters, unless a permit was obtained under its provisions. It also funded the construction of sewage treatment plants and recognized the need for planning to address nonpoint-source pollution problems.

CONSERVATION RESERVE PROGRAM

Established in its current form in 1985 and administered by USDA Farm Service Agency, the Conservation Reserve Program (CRP) is the latest version of long-term land retirement programs used in the 1930s and 1960s. The CRP provides farm owners or operators with an annual per-acre rental payment and half the cost of establishing a permanent land cover, in exchange for retiring environmentally sensitive cropland from production for 10 to 15 years. In 1996, Congress reauthorized CRP for an additional round of contracts, limiting enrollment to 36.4 million acres (14.7 million ha) at any time. The 2002 Farm Act increased the enrollment limit to 39 million acres (15.8 million ha). Producers can offer land for competitive bidding based on an environmental benefits index during periodic signups or automatically enroll more limited acreages in such practices as riparian buffers, field windbreaks, and grass strips on a continuous basis. The CRP is funded through the Commodity Credit Corporation.

improved under grass following its conversion from tilled cropland, including the lack of soil disturbance, slower decomposition of organic matter, enhanced soil structure, and greater biological diversity and organic resources. Other reasons for improved soil quality under grass are the continual input of organic matter from roots and the daily input of biochemical compounds secreted by roots (termed *rhizodeposition*, i.e., deposits from roots).

During the past century, an abundance of research has been conducted to illustrate the positive effects of grass on soil properties and processes. The following paragraphs highlight some key results. In South Dakota, for example, water runoff and soil loss were considerable following plowing of an alfalfa–smooth bromegrass (*Bromus inermis* Leyss.) field but nearly nonexistent if managed with no tillage or remaining in forage production (Table 7–3; Lindstrom et al., 1998). In Iowa, water runoff and soil loss were always reduced at the edge of fields with a grass buffer strip compared with open fields, even under a variety of surface conditions (Table 7–4; Gilley et al., 2000). These studies illustrate that whether grasses are planted across an entire field or simply in strips within a field, they can significantly reduce water runoff and soil loss.

Soil organic matter and its biologically active components are often much greater under long-term grass pastures than under cropland. In Texas, soil organic matter, soil microbial biomass (weight of microorganisms per unit mass of soil), and the amount of carbon that is decomposable under ideal decomposition conditions (potentially mineralizable carbon) were greater under grass pasture than under cultivated cropland in the surface 8 inches (20 cm) of soil (Table 7–5; Franzluebbers et al., 1998). In New Zealand, total nitrogen in the surface soil and the stability of soil aggre-

Table 7–3. Water runoff and soil loss as affected by tillage and land use from a Poinsett soil in South Dakota (data from Lindstrom et al., 1998). Values are means ± standard deviation. (1 ton/acre = 2.24 tonne/ha)

Treatment	Runoff	Soil loss	Surface cover
	% of rainfall	ton/acre	%
Plowed	45 ± 29	5.6 ± 3.6	2
No tillage	1 ± 1	<0.1	79 ± 10
Sod cover	0	0	100

gates were greater under grass than under conventional-tillage cropping (Table 7–6; Haynes, 1999). These studies demonstrate that soil under grass is enriched in organic matter, stable in structure, and able to supply a greater quantity of nutrients to plants.

Accumulation of soil organic matter with perennial grasses and legumes often prevents leakage of nitrate from soils, which can threaten water quality. Some perennial grasses extend their roots deep into the soil, often to a depth of 5 feet (150 cm), and more than annual crops to capture nitrate before it leaches below the root zone. Nitrate that is accumulated by plants is converted to protein, which is subsequently deposited onto the soil surface in the form of organic nitrogen as senescent plant parts in unharvested systems, or it is removed mechanically or by grazing animals and deposited as manure in harvested grass systems.

Research in the U.S. Corn Belt (Randall and Mulla, 2001) has shown that the nitrate lost from tiles draining agricultural fields in alfalfa or the CRP is often only a fraction of the nitrate lost from row cropping systems of corn and soybean (Table 7–7). When land under CRP is converted to cropland, corn and soybean yield can be enhanced during the first few years due to release of nutrients stored in soil organic matter, as well as because of improved soil biological and physical properties. Unfortunately, the release of nutrients following grassland termination can also contribute to nitrate loss through the root zone if appropriate rotation or tillage systems are not used. Diversifying crop rotations with species that have different rooting habits and reducing the

Table 7–4. Water runoff and soil loss as affected by the presence of six-year-old, 2.4-foot-wide switchgrass filter strips at 50 foot intervals within fields in Iowa (data from Gilley et al., 2000). Values are means ± standard deviation. (1 ton/acre = 2.24 tonne/ha; 1 ft = 30 cm)

Field management	Presence of grass filter strip	Slope	Surface cover	Runoff	Soil loss
		%	%	% of rainfall	ton/acre
Conventional tillage with crop residues removed	No	10	4 ± 1	53 ± 15	6.6 ± 2.3
	Yes	12 ± 3	4 ± 2	31 ± 19	2.4 ± 2.6
Conventional tillage with crop residues	No	13 ± 1	37 ± 17	19 ± 18	0.5 ± 0.5
	Yes	11 ± 2	30 ± 15	15 ± 16	0.2 ± 0.3
No tillage with crop residues	No	13 ± 2	78 ± 15	10 ± 13	0.2 ± 0.2
	Yes	13 ± 2	80 ± 9	5 ± 7	0.1 ± 0.1

Table 7–5. Soil organic matter, soil microbial biomass carbon, and potentially mineralizable carbon under bermudagrass pasture and cropland conditions in south-central Texas (data from Franzluebbers et al., 1998). Values are means ± standard deviation. (1 ton/acre = 2.24 tonne/ha; 1 lb/acre =1.12 kg/ha)

Management	Soil organic matter	Soil microbial biomass	Potentially mineralizable carbon
	ton/acre	lb/acre	lb/acre/day
Conventional tillage	17 ± 2	1393 ± 158	20 ± 4
No tillage	22 ± 1	1725 ± 156	28 ± 4
Grass pasture	38	3000	44

Table 7–6. Total nitrogen in the surface inch of soil, nitrogen uptake by perennial ryegrass during two months of growth, and soil aggregation characteristics (micro- to macrosize aggregates) from a soil in New Zealand (data from Haynes, 1999). (1 lb/acre =1.12 kg/ha)

Treatment	Total soil nitrogen	Nitrogen uptake	Macroaggregates	Mesoaggregates	Microaggregates
	lb/acre	lb/acre			
Conventional-tillage cropping	696	12	12	41	47
Grass pasture for 5 years	842	17	51	28	21
Grass pasture for 20 years	1248	22	54	26	20

Table 7–7. Average nitrate–nitrogen loss through tile drains from different agricultural management systems in Minnesota during four years (data from Randall and Mulla, 2001). (1 lb/acre =1.12 kg/ha)

Continuous corn	Corn–soybean rotation	Alfalfa	Conservation Reserve Program
lb nitrogen/acre/year			
48	45	2	1

disturbance of surface soil with reduced or no-tillage practices can lower the production of nitrate from the decomposition of soil organic matter.

Nutrient and fecal-borne bacterial contamination of surface and groundwater are now recognized as water-quality concerns. One of the environmental concerns with the rising production of manure from CAFOs and the dwindling land devoted to pastures in the eastern United States is the resulting high application rate of animal manures to the limited land area considered suitable for land application. In such cases, educating farmers and custom manure applicators about the benefits of applying stored manure more evenly across a diversity of pastures could reduce application rates on annual cropland.

Repeated application of a high rate of animal manure to pasture has led to nutrient-enriched surface soil, however, which can contribute to water-quality deterioration with excessive rainfall. Although pastures are effective at keeping soil in place, dissolved or suspended nutrients can flow across the landscape into receiving bodies, and vegetated buffers are ineffective at trapping these contaminants. Dissolved phosphorus in water runoff is of particular importance because it directly feeds algae in water, leading to eutrophication, an increase in nutrients that leads to excessive plant growth. Furthermore, decomposition of algal blooms reduces oxygen levels in water, leading to suffocation of fish and other aquatic organisms. Similarly, fecal-borne pathogen transport across the landscape can occur in runoff water, particularly when manure is applied shortly before large rainfall events. Having sufficient time for animal manures to interact with surface soil and its resident population of decomposer microorganisms will usually result in less risk of dissolved nutrients and fecal-borne pathogens leaving the point of application. Similar nutrient losses are also possible from commercial fertilizers. Consequently, nutrient application to grasslands and cultivated soils should be based on regular soil testing to minimize the potential for excessive nutrient loading. Management practices to minimize nutrient transport with water include shallow manure and nutrient incorporation and restricting access to susceptible fields or pastures before winter runoff events.

OPPORTUNITIES FOR FUTURE AGRICULTURAL SYSTEMS

Increased interest in using grasses to protect soil and water resources and as a source of biomass for renewable energy production has heightened public awareness of grass. The government's Soil Bank program in the 1950s and, more recently, the CRP provide two examples whereby landowners and operators were encouraged to reestablish grasslands to reduce soil erosion. Grasses and legumes are also being promoted as cover crops, living mulches, or components of silviculture or agroforestry systems. Driven by public concern over unstable and limited fossil fuel supplies, interest in grass-based agricultural systems is rapidly increasing to provide biomass feedstocks for biofuel production. The most effective way to ensure that all of the benefits of grass are captured in future agricultural systems is to target and incorporate them into diverse, landscape-based cropping systems. The following sections outline a few of the ways that grasses could be incorporated in the landscape.

Conservation Reserve Program

The CRP, initiated following passage of the 1985 Food Security Act, is an example of how policy encouraged reestablishment of grasslands primarily to reduce soil erosion on former cropland. Secondary CRP goals included protecting the nation's ability to produce food and fiber, improving water quality, reducing sedimentation, fostering wildlife habitat, curbing production of surplus commodities, and providing income support for farmers. In exchange for retiring their highly erodible land for 10 years, the USDA paid CRP participants an annual per-acre rent and one-half of the cost of establishing a permanent land cover. Many lessons were learned through this program, including that enrollment improved soil quality, reduced soil erosion, and enhanced wildlife habitat. In addition, it was clear that if the CRP land is returned to crop production, it should be managed using no-tillage practices to maintain the soil quality benefits (Karlen et al., 1998). High grain prices during the early 21st century are once again enticing producers to return this land to crop production, which may reverse the progress that was made in stabilizing this land resource.

Integrated Agricultural Systems

Grasses and legumes also can be incorporated into current cropping systems as cover crops, as living mulches, or through silviculture and agroforestry practices. Cover crops are simply defined as crops that cover the soil. Several plant species can be used as cover crops depending on water availability and latitude. For the midwestern United States, where the growing season before and after the primary corn and soybean crops is very short, small grains such as oat, barley, and rye are most effective. Seed of these plant species is relatively inexpensive, plant stands are easy to establish, seedlings grow rapidly during cool weather and tolerate moderate frost, and the species do not pose a threat as weeds for the subsequent cash crops. Cover crops have been shown to reduce erosion, capture residual soil nitrate and lower leaching losses, increase soil organic matter, provide early-season weed control, and provide forage in diversified farming systems.

Perennial legumes such as alfalfa, various clover (*Trifolium* spp.) species (e.g., crimson, kura, red, white, alsike, and ladino), and hairy vetch (*Vicia villosa* Roth) are potential candidates for living mulches in various parts of the United States. In addition to the benefits associated with cover crops, these legumes can provide fixed nitrogen that can substantially reduce the fertilizer requirements for subsequent cash crops. Also, after establishment, these crops do not have to be replanted on an annual basis. Greater diversity of vegetation can increase the abundance and effectiveness of natural enemies of insect pests. For example, Prasifka et al. (2006) reported that using alfalfa and kura clover (*Trifolium ambiguum* M. Bieb.) as living mulches in corn and soybean increased predator insect abundance and consumption of European corn borer (*Ostrinia nubilalis* Hübner) pupae. Although living mulches may compete with the primary crops for early-season water and nutrient uptake, this is not the problem it once was because with modern herbicide technology, the living mulches can often be suppressed until the cash crops are growing rapidly.

Silviculture and agroforestry offer other options for integrating grasses and legumes into cropping systems that include tree species grown for lumber, fruit, or nuts. These systems are designed to produce trees, tree products, forage, and livestock in the same physical land area. These systems offer economic benefits for landowners and ecological benefits for water, soils, and wildlife. Examples of these systems include *alley cropping*, whereby an annual or perennial crop is grown between rows of high-value trees; *forest farming*, in which high-value specialty crops such as ginseng (*Panax* spp.), shitake mushrooms (*Lentinula edodes*), herbs, or decorative ferns and willows (*Salix* spp.) are grown beneath trees that provide the required shade and micro-environment; *windbreaks*, whereby trees are planted to prevent soil erosion and crop damage; *riparian buffers* on

Kura clover ground cover under corn in mid-September just before silage harvest. (Photo by Ken Albrecht)

CORN PRODUCTION IN KURA CLOVER LIVING MULCH: FARMING FOR NITROGEN AND THE ENVIRONMENT

Ken Albrecht

Alfalfa and corn, grown in rotation, have long been the primary high-quality feeds to support the dairy industry in the North-Central United States. However, conventional tillage, and especially removal of essentially all plant residue with corn silage production, can result in excessive erosive soil loss and nutrient runoff from fields to surface water. The recent interest in utilizing corn stover—which is now returned to the soil to provide cover that reduces wind and water erosion—for cellulosic ethanol production has further prompted the need for alternative soil conserving systems. Furthermore, the ever-increasing cost of nitrogen fertilizer encourages the search for cropping systems that rely on biologically fixed nitrogen.

Legume living mulches have been tested in the northern United States as a means to meet nitrogen requirements of corn, but most perennial legumes evaluated reduced corn yields or failed to recover after corn harvest. Kura clover (*Trifolium ambiguum* M. Bieb.) seems to be ideally suited to serve as living mulch. It is extremely persistent through frigid winters and produces rhizomes that allow it to fill in gaps that may otherwise be invaded by weeds. Research by University of Wisconsin–Madison scientists has demonstrated that with adequate suppression, kura clover can be managed to provide minimal competition to corn and that this system results in reduced soil erosion compared to conventional corn production systems. Furthermore, all of the nitrogen required for corn production appears to be available through the suppressed clover, and kura clover recovers to full production by June the following season.

Legume living mulch could allow sustainable expansion of corn production to meet growing demand for human and livestock consumption as well as for biofuel production.

land adjacent to streams, lakes, and wetlands that are managed for trees, grasses, and/or shrubs; and *silvopasture* systems that combine timber with forage and livestock production. Managing the interactions among the timber, forage, livestock, and row-crops is the key for creating sustainable systems with environmental benefits and a diversity of marketing opportunities that stimulate rural economic development.

Green Payments for Conservation

The evolution of current U.S. cropping systems was based on various forms of financial compensation that were made available to landowners and operators to help reduce risk and ensure a stable supply of agricultural products. This approach focused on crop yield as the primary indicator of success and became referred to as *commodity payments*. The 1996 Farm Bill began to change this relationship by allowing farmers to have more flexibility in their cropping choices through the Freedom to Farm Act. Real change began with the 2002 Farm Bill when the Environmental Quality Incentives Program and Conservation Security Program (CSP) increased the emphasis on paying for specific conservation practices, with the goal as having measurable impacts on soil, water, and air quality.

The initial reaction to commodity or "green" payments was mixed because of the difficulty in measuring significant changes in environmental parameters. However, through research such as the USDA-Agricultural Research Service (ARS) Conservation Effects Assessment Project (CEAP) and tools such as the USDA-NRCS's Soil Conditioning Index and the ARS's Soil Management Assessment Framework, the concept of paying for conservation and achieving multiple endpoints is gaining support. Data showing that long-term rotations that include at least three years of forage had higher soil-quality ratings than continuous corn (Karlen et al., 2006) provide evidence in support of green payments.

Land Tenure and Ownership

In addition to the large decline in farm numbers during the past 60 years (see Table 7–1), a significant change in ownership or land tenure has occurred. Recent National Agricultural Statistics Service records show that in the upper Midwest, the amount of harvested farmland that is rented averages 62, 58, 56, 46, and 36% in Illinois, Indiana, Iowa, Minnesota, and Wisconsin, respectively. This landownership profile is important with regard to grass-based farming systems because ownership influences long-term versus short-term decisions.

In practice, land tenure influences many management decisions, including whether to invest in long-term grass-based crop rotations or to grow annual crops for which there is a well-developed infrastructure and immediate market. Should investments be made in soil amendments such as agricultural lime, which typically requires three to five years to return full benefits, if there is no guarantee a farmer can rent the same land next year? Furthermore, as the proportion of rented land increases within an area, there is often greater competition and higher capital costs to obtain more land. Uncertainty regarding land tenure can also result in much different strategic plans and attitudes toward investing in long-term conservation practices. Landownership and familiarity with the inherent differences from one field to the next often results in better land management, with greater incentives for long-term profitability and sustainability.

New Market Opportunities

One of the most promising changes in agriculture since *Grass: The 1948 Yearbook of Agriculture* was issued is the emergence of the bioenergy and bioproducts markets during the early 21st century. Driven by public concern over unstable and limited fossil fuel supplies, interest in grass-based agricultural systems is increasing rapidly to provide lignocellulosic feedstocks for these operations. This has tremendous potential for solving several problems, including bioenergy, water quality, air quality through carbon sequestration, soil quality through increased soil organic matter levels and decreased erosion, wildlife habitat, aesthetics, and rural economic development. Although the initial focus primarily has been on using crop residues (corn stover and/or wheat

FREEDOM TO FARM

The Federal Agriculture Improvement and Reform Act of 1996 decoupled government farm subsidy payments from both price and production and provided farmers with nearly complete planting flexibility. This shift in policy was an attempt to let the marketplace dictate acreage decisions for the period 1996 to 2002 because the Administration and Congress were not content with the former method of distributing payments and were not in consensus about the government's role in agriculture.

CONSERVATION SECURITY PROGRAM

The Conservation Security Program (CSP) is a voluntary conservation program that supports ongoing stewardship of private agricultural lands by providing payments for maintaining and enhancing natural resources. The CSP is authorized by the Farm Security and Rural Investment Act of 2002. Sign-up for the CSP uses a watershed approach rather than county or state lines. Watersheds are selected for inclusion in the program based on priority; however, the goal during the eight-year authorization period for CSP is to rotate through all of the nation's 2119 watersheds to provide an opportunity for all eligible participants to enroll. Between 2004 and 2006, over $230 million was spent on CSP, more than 15 million acres were enrolled, and 298 watersheds had been selected.

THE ENERGY POLICY ACT OF 2005

The Energy Policy Act of 2005 is a statute that was passed by the U.S. Congress on 29 July 2005 and signed into law by President George W. Bush on 8 August 2005. The Act increases the amount of biofuel (usually ethanol) that must be mixed with gasoline sold in the United States to triple the current requirement (7500 million gallons [28,390 million L] by 2012) and authorizes $50 million annually over the life of the bill for a biomass grant program.

straw) and perennials such as switchgrass (*Panicum virgatum* L.), many other options are available for development. Current evaluations of *Miscanthus* spp., fiber cane (*Saccharum officinarum*), reed canarygrass (*Phalaris arundinacea* L.), and legumes such as alfalfa are underway. The key for success, however, is to examine not only various plant species but also the landscape position where these plants would be best adapted, potential changes in soil water and nutrient balances, harvest, storage, and transportation issues, feedstock consistency, and processing qualities. The agricultural knowledge, science, and technology needed to successfully reintegrate grass-based land management into American farms exist. Increased diversity will ensure that soil and water resources are being used in an efficient and sustainable manner. The potential for government policies to stimulate this transition is in place with programs such as the CSP.

Projections for the Future

Based on these opportunities, what will our future agricultural landscapes look like, and how will forages and grasslands be incorporated into them? We suggest that the rapidly emerging technologies to use lignocellulosic materials for production of bioenergy and bioproducts offer an unprecedented opportunity to truly change the culture of agriculture in the United States and throughout the world. Building on examples from Coughenour and Chamala (2000), who discussed the development and adoption of conservation tillage and innovative cropping systems, the most notable change during the next 60 years will be to simultaneously address water quality, air quality, soil erosion, greenhouse gas emissions, wildlife habitat, aesthetics, transportation corridors, employment, rural communities, and the people living in these areas. To do so will require a well-planned, market-driven approach for selecting and integrating many different plant species into each landscape-based management unit. This will involve an expanded application of the technologies and methods developed for site-specific management of farm-scale soil, water, and crop management systems. For each location, we envision following an eight-step sequence:

Identify landscape characteristics using georeferenced technologies and methods.

Identify the landscape's important production and conservation issues.

Delineate critical areas requiring different crops and practices.

Identify suites of suitable crops, crop rotations, and conservation practices for each management area.

Develop a landscape-scale precision agriculture system (e.g., Kitchen et al., 2005).

Apply policies, educational efforts, and programs that address social and economic concerns for adopting and implementing the landscape-scale precision agriculture systems.

Monitor and document the new system's performance toward achieving production and conservation goals.

Reevaluate the system and make adaptive changes to improve its performance.

This approach would result in multiple subwatersheds where, beginning close to the stream, woody (e.g., *Populus*) species or buffers that function as long-term biomass sources would be established. Adjacent to this area, species such as miscanthus, reed canarygrass, or eastern gamagrass (*Tripsacum dactyloides*) could be used because these grasses have varying tolerances to wet soil conditions. Using perennials in this landscape position could lower nitrogen losses and contribute to carbon sequestration to help mitigate increasing concentrations of atmospheric carbon dioxide. In autumn, these perennials could provide a source of biomass for bioenergy or bioproducts, thus addressing at least three of the current natural resource issues (biomass production, carbon sequestration, water quality, etc.). Moving up the landscape a diversified rotation of annual and perennial crops would be used to meet food, feed, and fiber needs. Erosion could be partially mitigated by using cover crops and/or living mulches. In the upper portions of each watershed, intensive row crop production areas could be established using best management practices with the awareness that if fertilizer recovery was less than desired, there would be a substantial buffer/lignocellulosic production area lower on the landscape to capture residual nutrients and sediment. This vision is technologically feasible using global positioning systems, geographic information systems, remote sensing, and related technologies for precision or site-specific mapping and management. There will be adoption challenges, but many of these can be overcome by offering a combination of conservation and risk-management incentives. This approach may be more appealing to urban and suburban taxpayers because adopting such landscape management systems would simultaneously address energy, water quality, carbon sequestration, wildlife habitat, aesthetics, food, feed, and fiber production. Implementing this vision will markedly change agriculture throughout the United States, ultimately leading to far reaching soil and water conservation benefits that rely on grass-based systems as their foundation.

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